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Numerical modeling of parallel-plate based AMR

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Outline

- The Danish effort in magnetic refrigeration
- Focus on the modeling
- Results from both experiment and modeling
- Discussion

Risø's work on magnetic refrigeration

Partnership between

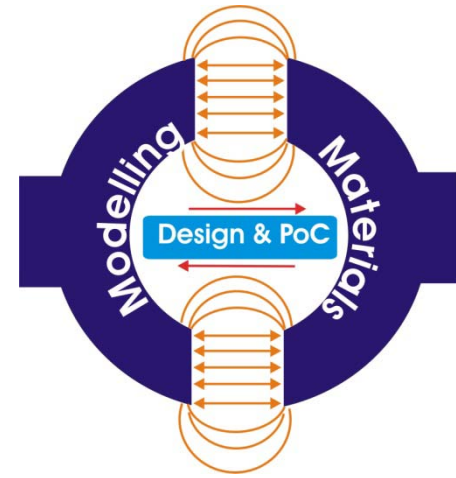


Duration: 4 years

- Starting date: 01.01.2007
- Ending date: 31.12.2010

Funding: €2.6M

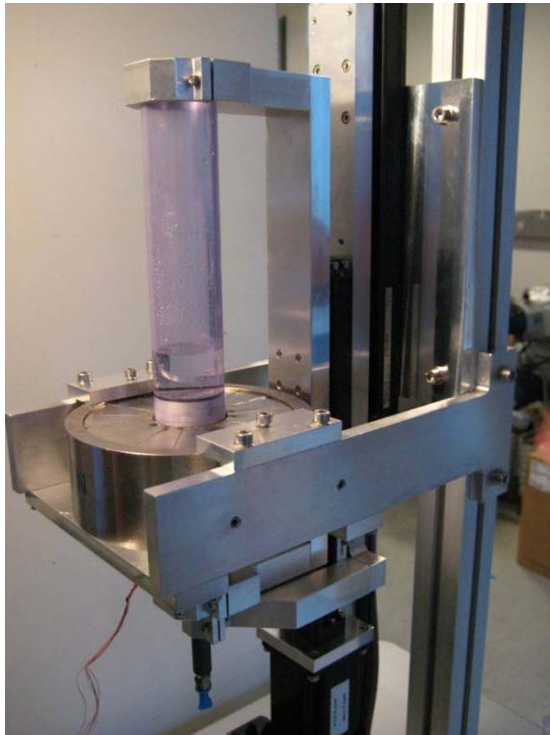
- 5 Ph.D. students
- 3 Postdocs



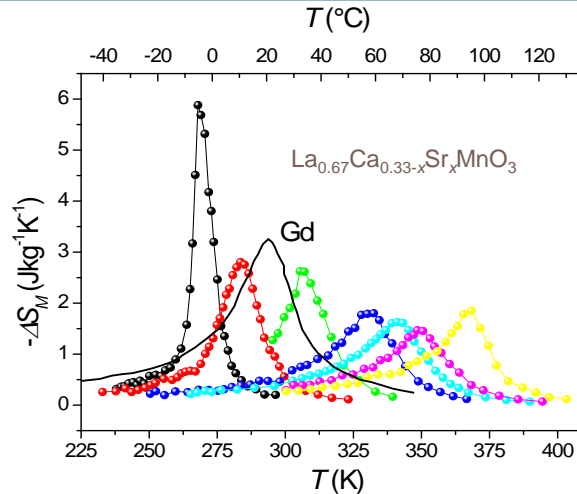
Challenges

Demonstrate cost-effective systems at commercially relevant temperature spans with high efficiency and environmentally friendly materials

Configuration of our effort



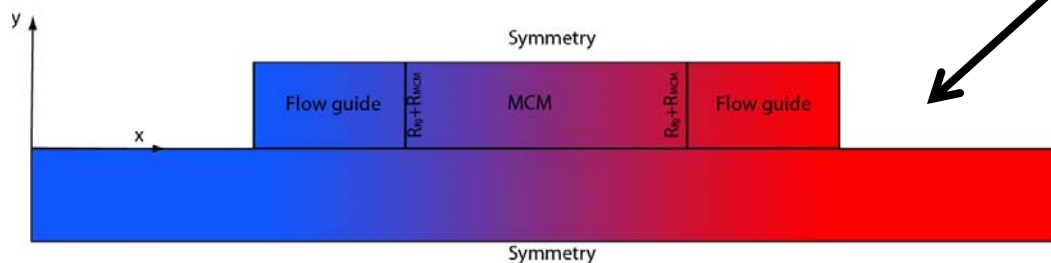
Development of prototype



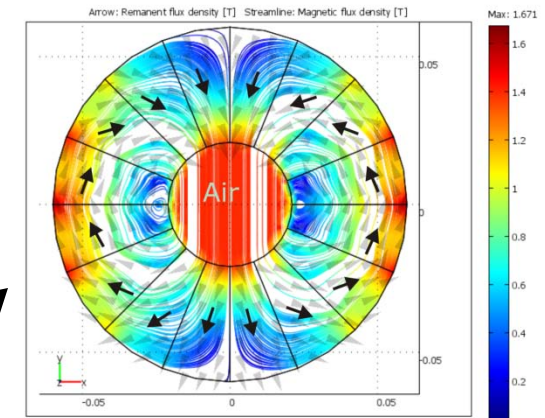
Materials research:

- New materials
- Characterization, evaluation and processing of relevant materials

Modeling of both AMR and permanent magnet

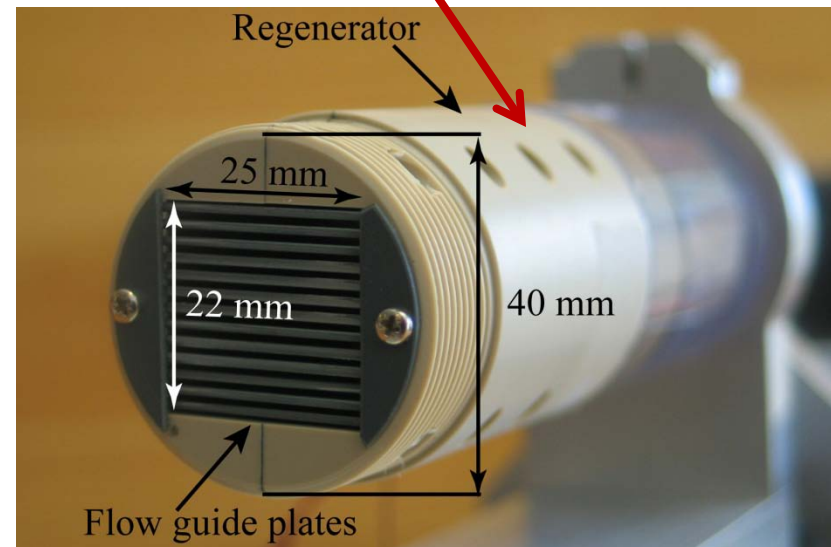
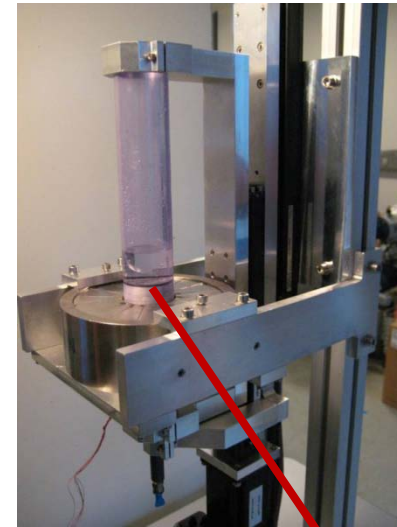


Linear system
Halbach cylinder



Details on the experiment

- Parallel plate based AMR
- Reciprocating
- Permanent magnet
- Materials used include Gd and LaCaSrMnO_3
- Plate thickness from 0.3 to 0.9 mm
- Channel thickness from 0.5 to 1.0 mm

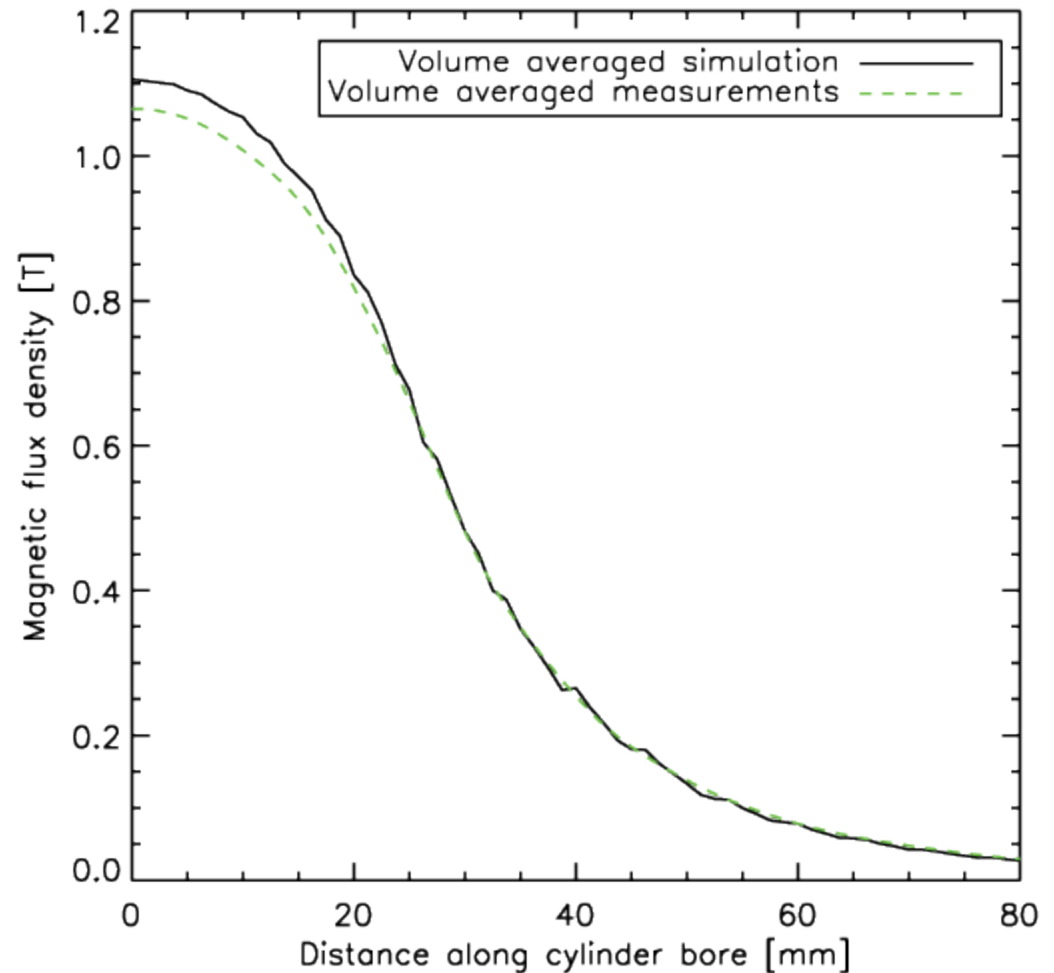
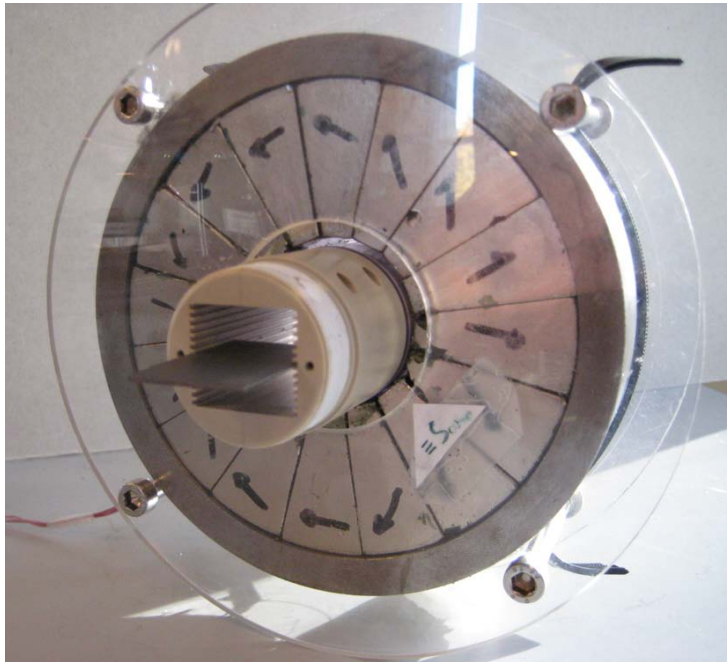


Plates for the regenerator

Example of $\text{La}_{0.67}\text{Ca}_{0.26}\text{Sr}_{0.07}\text{Mn}_{1.05}\text{O}_3$ plates
(40x25x0.3 mm)



The permanent Halbach magnet

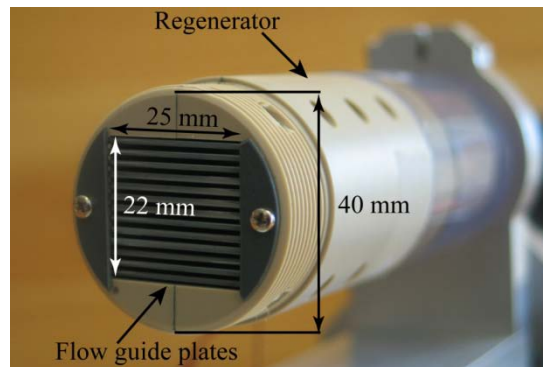
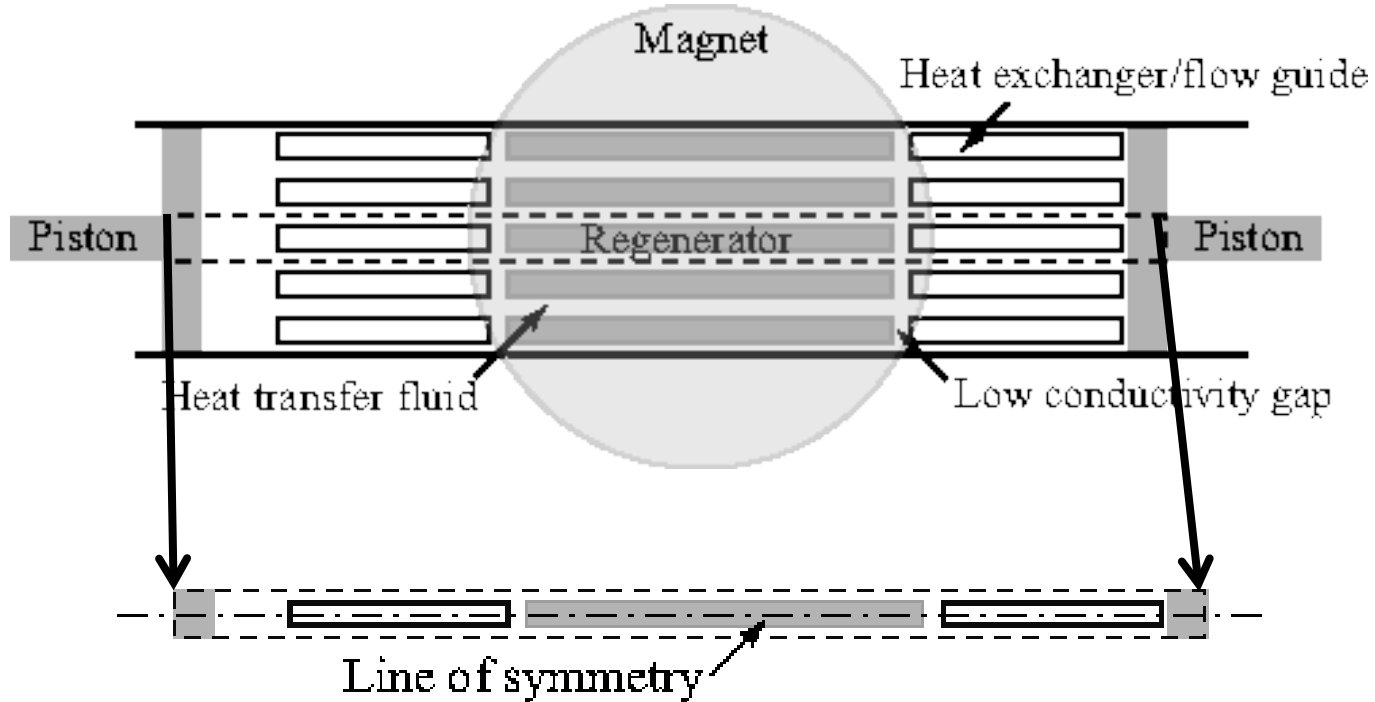


Numerical AMR modeling

Key features of our numerical AMR model

- 2.5-dimensional
- Parallel-plate based
- Versatile
- Fast!

Schematic of the model



Details of the model

$$\rho_{MCM} c_{p,MCM} \frac{\partial T_{MCM}}{\partial t} = k_{MCM} \nabla^2 T_{MCM} + Q_{MCE} + \frac{T_{\infty} - T_{MCM}}{dV \sum R_{MCM}} + Q_{bdry}$$

$$\rho_{fg} c_{p,fg} \frac{\partial T_{fg,1}}{\partial t} = k_{fg} \nabla^2 T_{fg,1} + \frac{T_{\infty} - T_{fg,1}}{dV \sum R_{fg}} + Q_{bdry}$$

$$\rho_{fg} c_{p,fg} \frac{\partial T_{fg,2}}{\partial t} = k_{fg} \nabla^2 T_{fg,2} + \frac{T_{\infty} - T_{fg,2}}{dV \sum R_{fg}} + Q_{bdry}$$

The diagram illustrates a cross-section of a system with three main layers: Flow guide, MCM, and Flow guide, all situated within a larger Fluid domain. The x-axis is horizontal, and the y-axis is vertical. Thermal resistances are indicated at various interfaces: $R_{fg} + R_{fluid}$ at the boundaries of the flow guide layers, $R_{fg} + R_{MCM}$ at the interfaces between the flow guide and MCM layers, and $R_{MCM} + R_{fluid}$ at the boundaries of the MCM layer. The fluid domain is labeled $R_{pist} + R_{conv}$ at the top and bottom boundaries. Arrows indicate the symmetry of the system.

$$\rho_{fl} c_{p,fl} \left(\frac{\partial T_{fl}}{\partial t} + u \cdot \nabla T_{fl} \right) = k_{fl} \nabla^2 T_{fl} + \frac{T_{\infty} - T_{fl}}{dV \sum R_{fl}} + Q_{bdry}$$

Details of the model



The diagram illustrates a microfluidic device layout. A central horizontal section is labeled "Plastic tube" at both the top and bottom. This central section is divided into five segments: "Fluid", "Flow guide", "MCM", "Flow guide", and "Fluid". The "MCM" segment is the widest, while the "Flow guide" and "Fluid" segments are narrower. On the left and right sides of the central section are vertical sections labeled "Piston".

Resistance components are indicated by text within the segments:

- Fluid segments (left and right):** Top and bottom labels are $R_{\text{fluid}} + R_{\text{pl}} + R_{\text{conv}}$. The right "Fluid" segment also has a vertical label $R_{\text{pist}} + R_{\text{conv}}$ on its right side.
- Flow guide segments (left and right):** Top and bottom labels are $R_{\text{fg}} + R_{\text{pl}} + R_{\text{conv}}$. The right "Flow guide" segment also has a vertical label $R_{\text{MCM}} + R_{\text{fg}}$ on its right side.
- MCM segment:** Top and bottom labels are $R_{\text{MCM}} + R_{\text{pl}} + R_{\text{conv}}$. It has vertical labels $R_{\text{MCM}} + R_{\text{fg}}$ on both its left and right sides.
- Piston segments (left and right):** A vertical label $R_{\text{pist}} + R_{\text{conv}}$ is located on the left side of the left "Piston" segment.

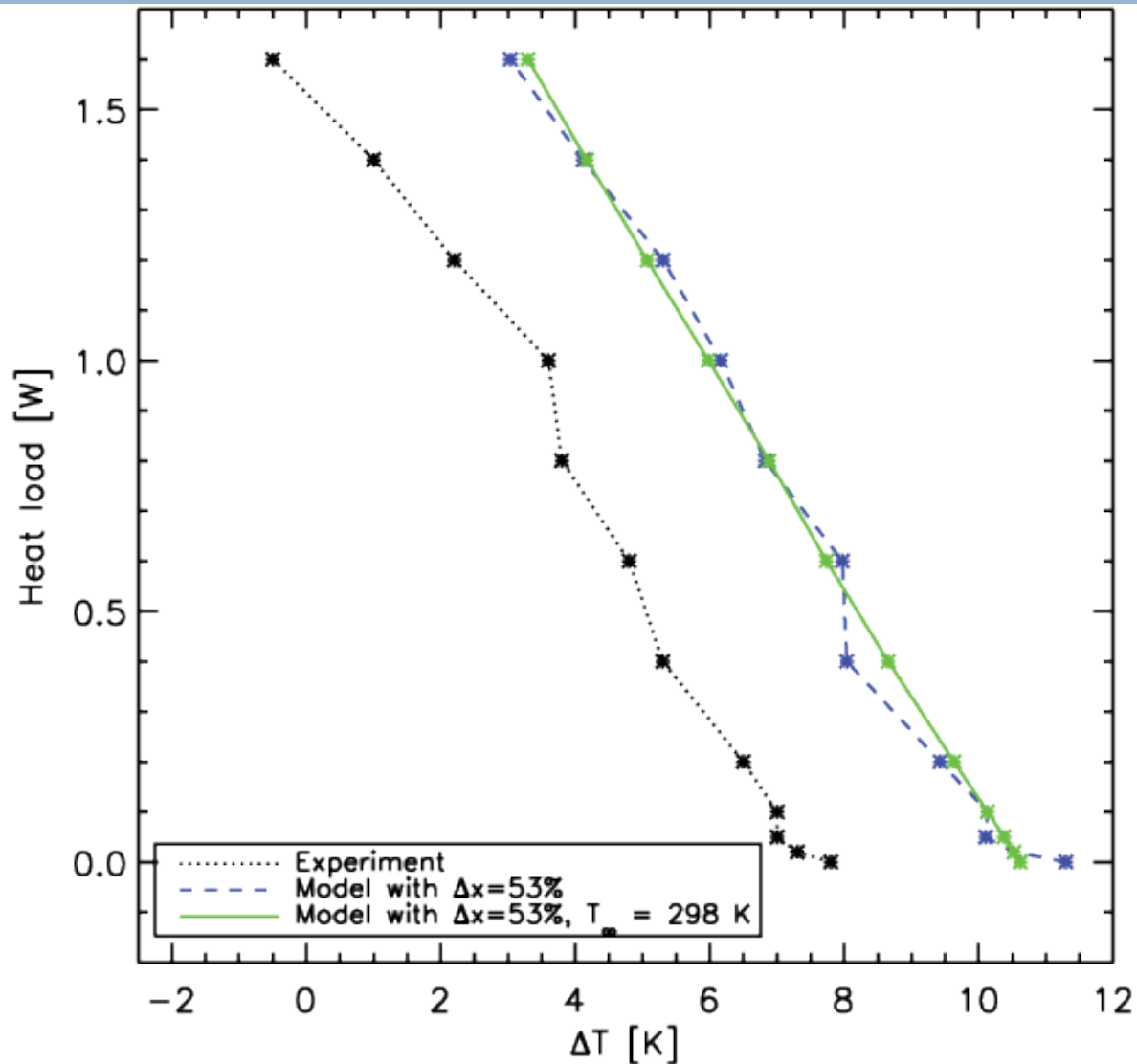
Coordinate axes are shown at the top left: a horizontal arrow pointing right is labeled "x", and a vertical arrow pointing down is labeled "z".

Experiments and modeling

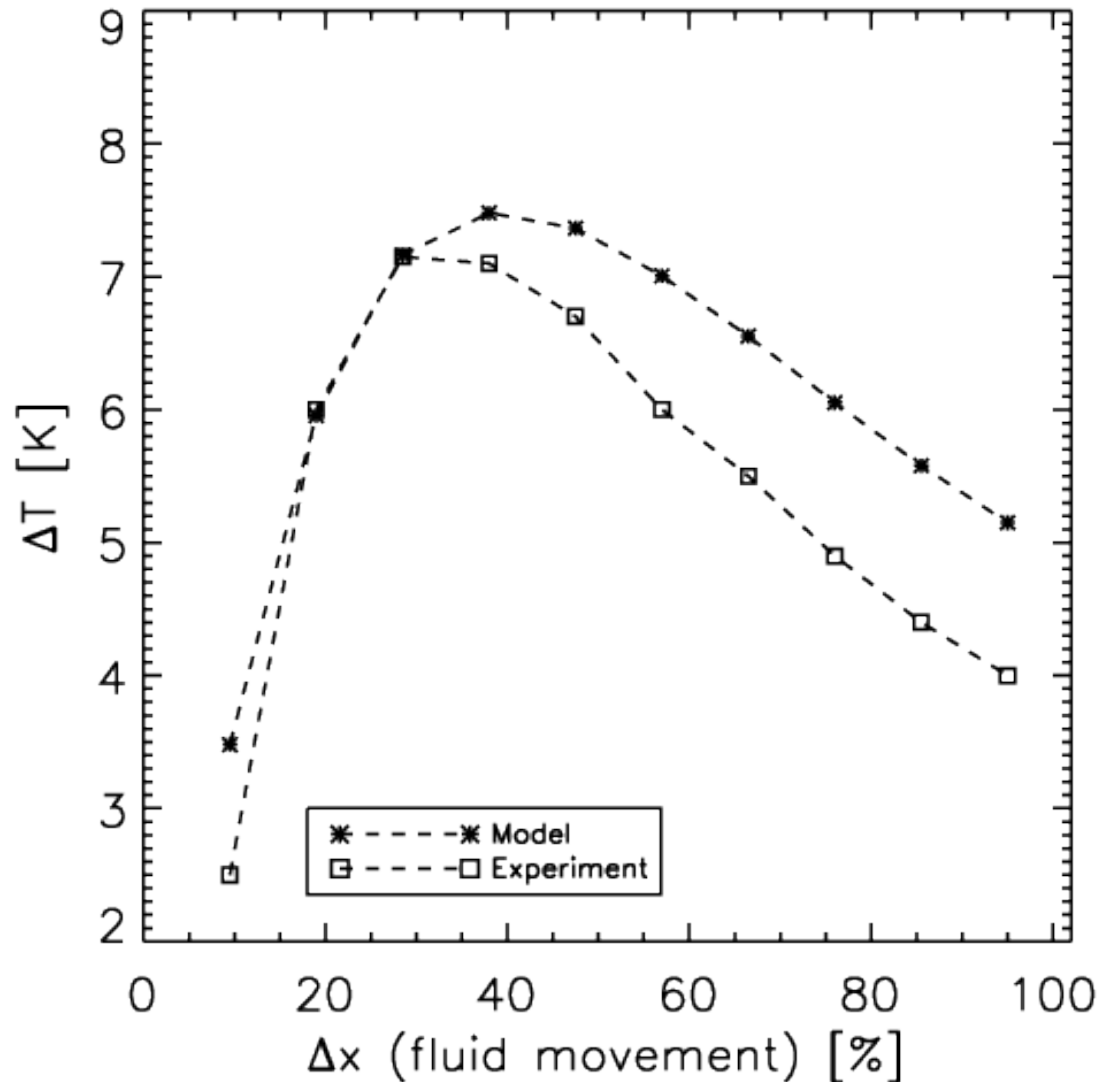
Each experiment was configured as follows

- 13 plates of commercial grade Gd (92 g)
- Plate thickness: 0.9 mm
- Channel thickness: 0.8 mm
- A cycle timing of 9 s

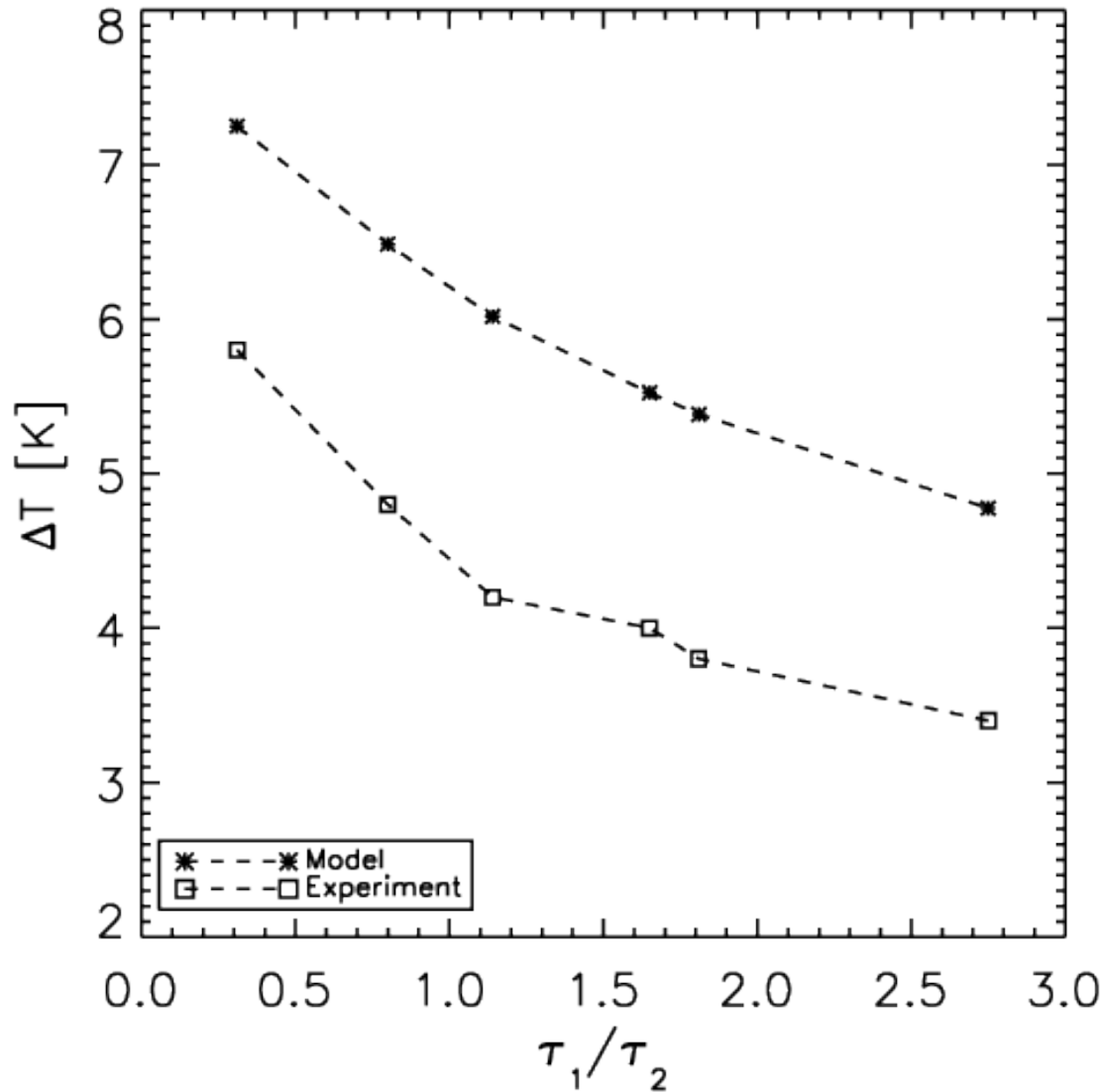
Heat load results



Fluid movement results



Timing results



Summary and Conclusion

- A versatile experimental AMR was presented
- A corresponding advanced 2.5D numerical model was described
- Selected results from experiment and model were compared and to a certain extent the agreement is satisfactory

Future work

- Further development of the model to include e.g. passive regeneration and composite materials
- Present large range of experiments with corresponding modeling of various materials
- Detailed study of demagnetization effects
- Work on composite materials

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